Solar and Wind Energy Assessment, Prediction, and Projection

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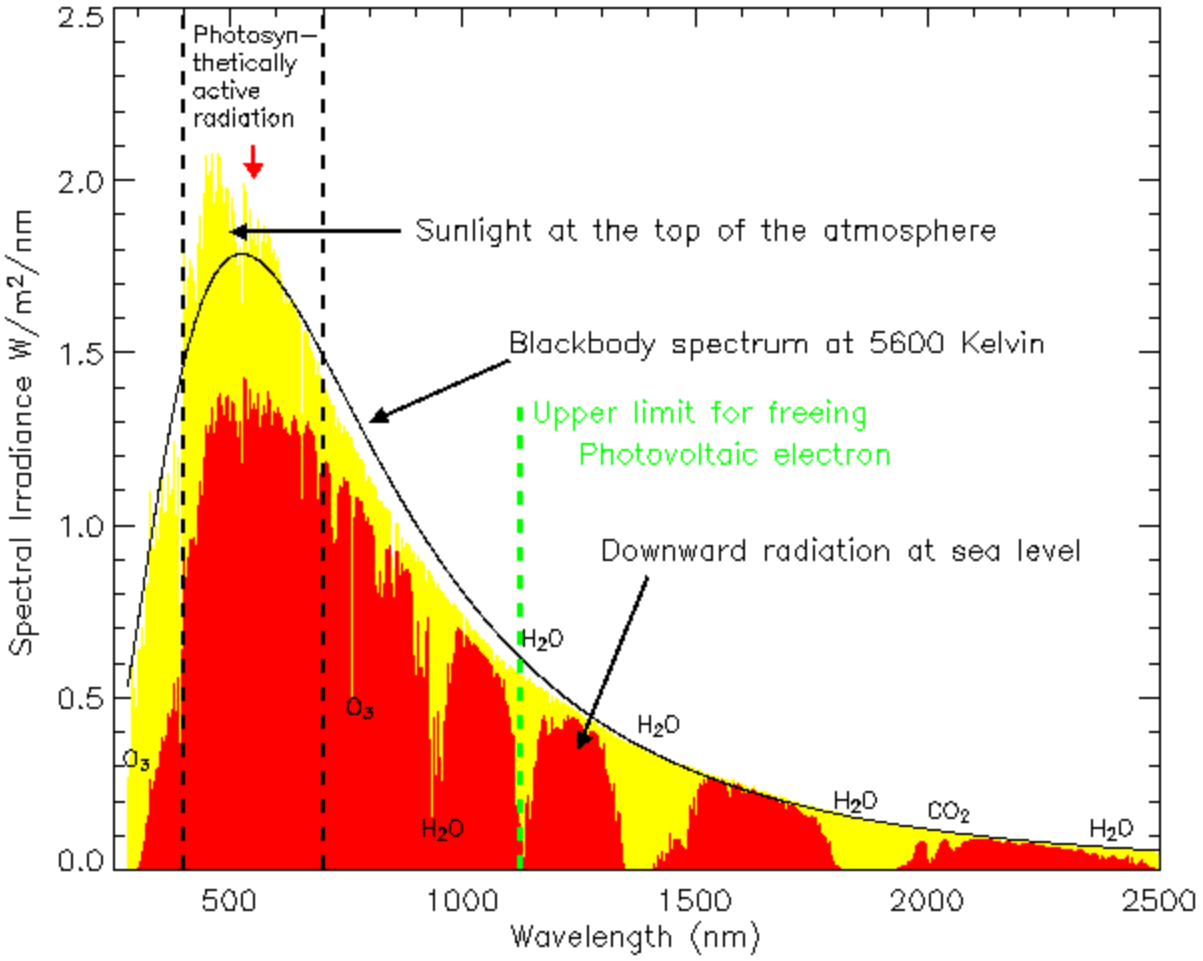
How can we help renewable energy developments?

- Acquire meteorological data for solar and wind energy calculations from satellite measurements.
- Assimilate satellite radiance in support of weather forecasting and use the forecasting data for solar and wind energy prediction.
- Analyze reanalysis data for solar and wind energy assessments and study the trends in global and regional solar and energy distributions.

Solar Energy

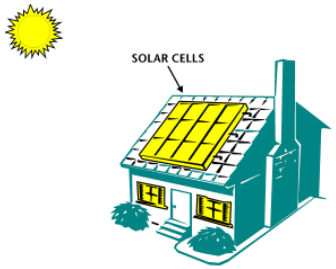
Solar spectral irradiance



Surface Solar Radiation Products

- Total and direct solar radiation flux (0.25 – 4.0 µm)
- Photovoltaic cell (0.25 – 1.125 µm)
- Photosynthetically active radiation (0.4 – 0.7 µm)

solar thermal plant



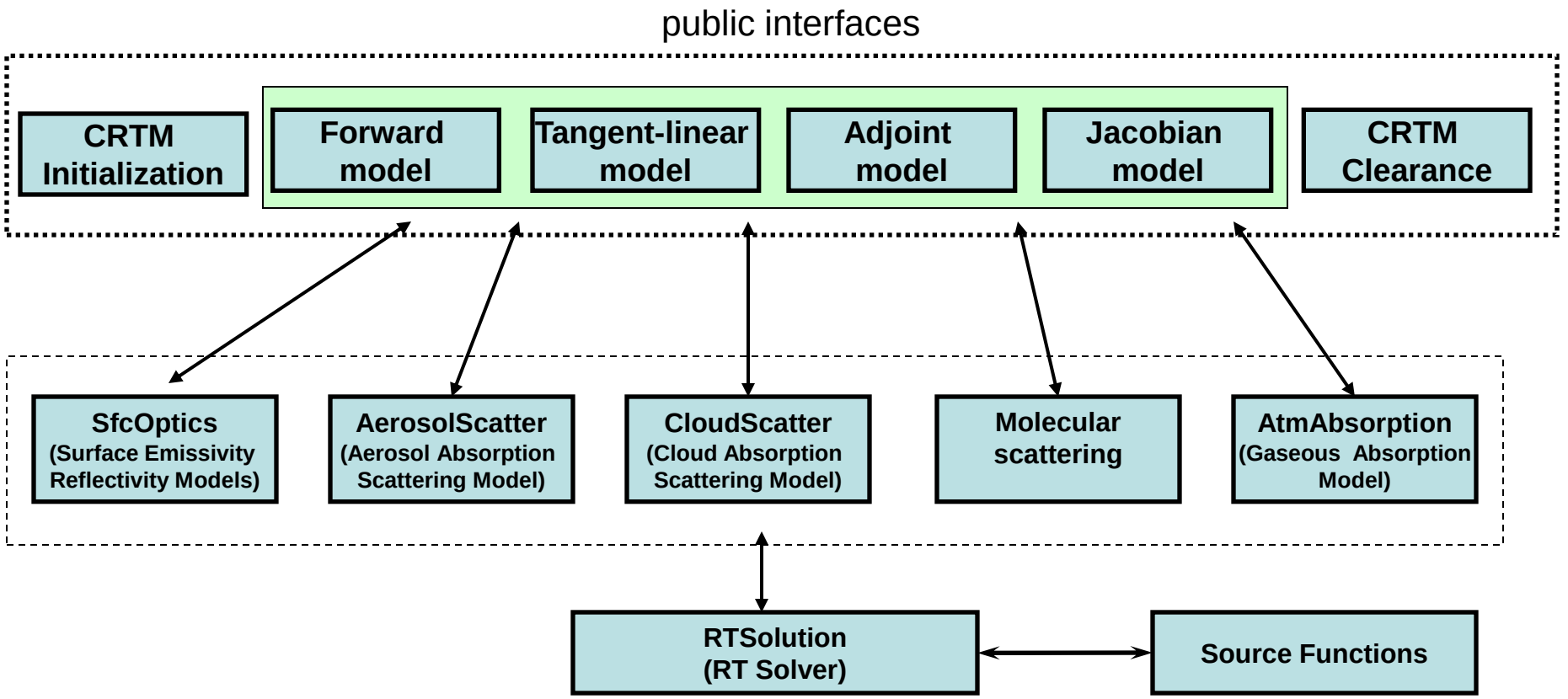
Solar panel
Only photons having enough energy can free electrons.

Bio-diesel

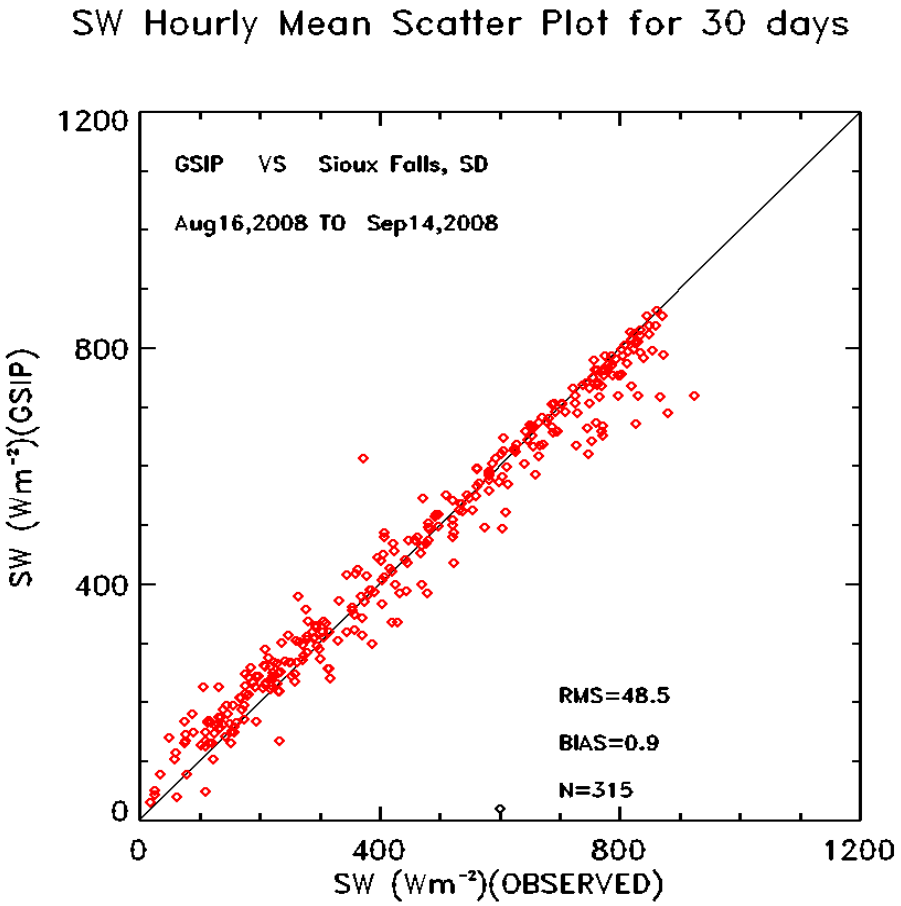
Credit to google search for the images.

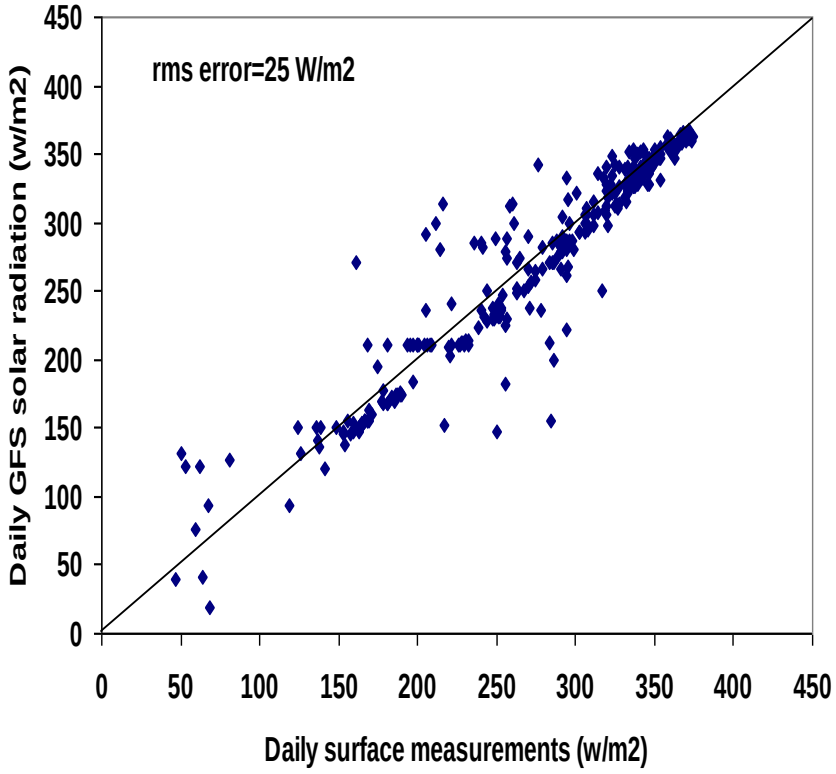
Various schemes for calculating different solar components are critical. Solar water heater needs accurate total flux, solar mirror collector only use direct flux, and photovoltaic cell uses energy less than 1.12 µm.

CRTM Major Modules



GOES and NCEP shortwave radiation agree well with surface measurements





Laszlo et al., GOES Surface and Insolation Products, CDR, 2008

NCEP surface SW vs surface measurements at Arizona

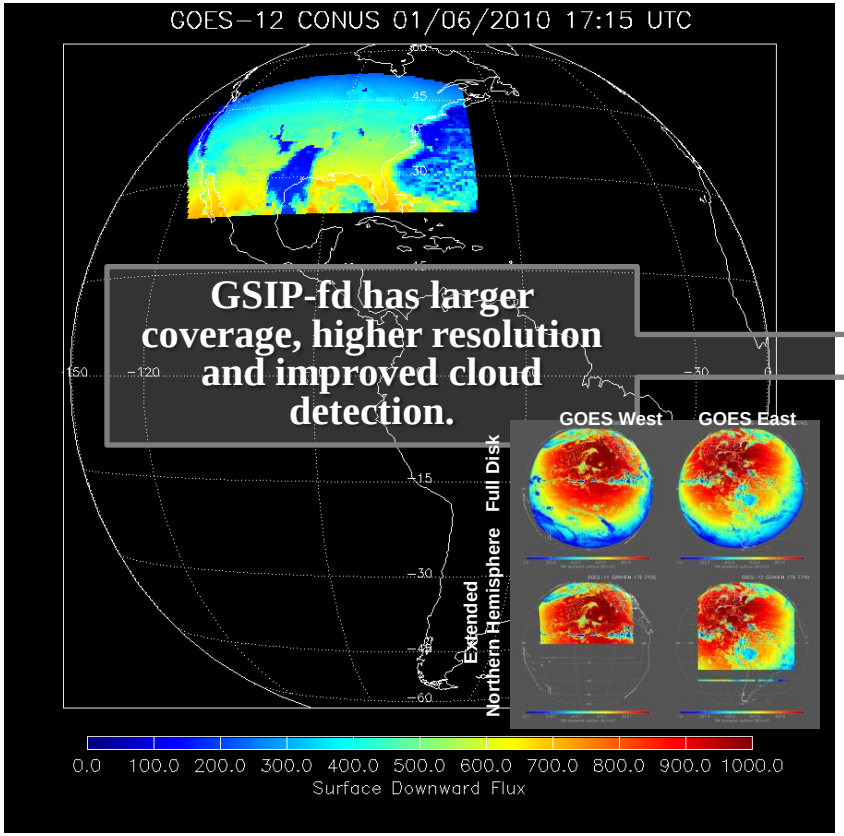
Characteristics of GOES Surface Solar Radiation Products

	Current		*Future*
Product	**GSIP-CONUS**	**GSIP-fd**	**GOES-R/ABI***
Domain	CONUS	• Northern Hemisphere (NH) • Full Disk (FD)	• CONUS (C) • Full Disk (FD) • Mesoscale (M)
Spatial Resolution	~56 km (0.5x0.5 degrees)	~14 km (1/8x1/8 degrees)	C: 25 km FD: 50 km M: 5 km
Temporal Resolution	instantaneous	instantaneous	instantaneous
Refresh rate	1 hour	1 hour (NH) 3 hours (FD)	1 hour
Latency	50 minutes	50 minutes	54 minutes

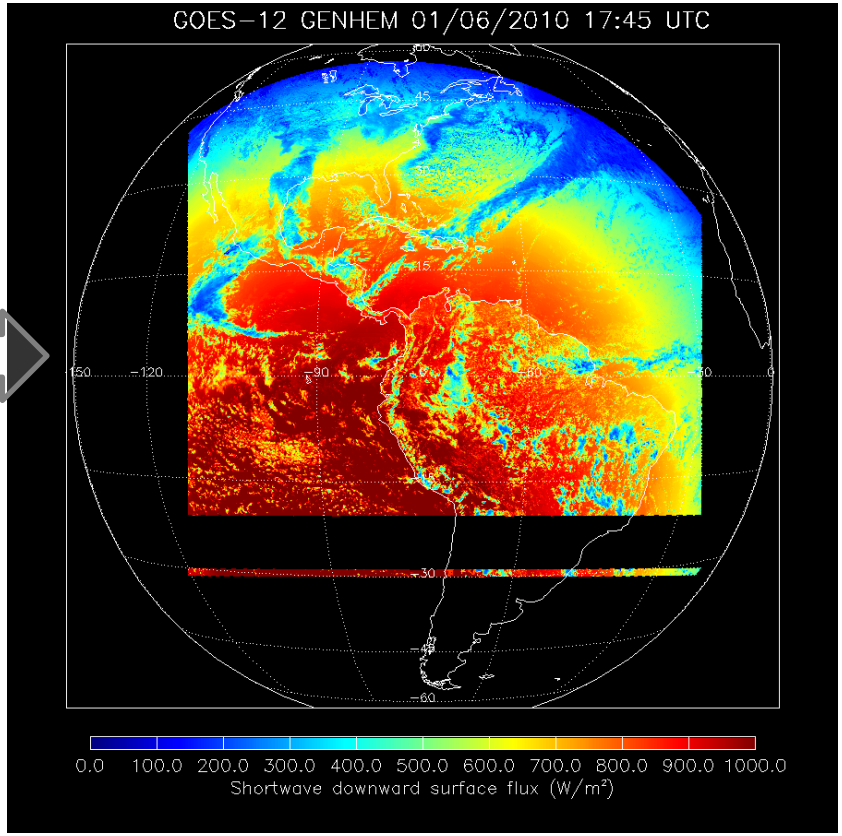
***Reflects current requirements; does not meet SE needs**

GSIP-fd Product Example

GSIP-CONUS

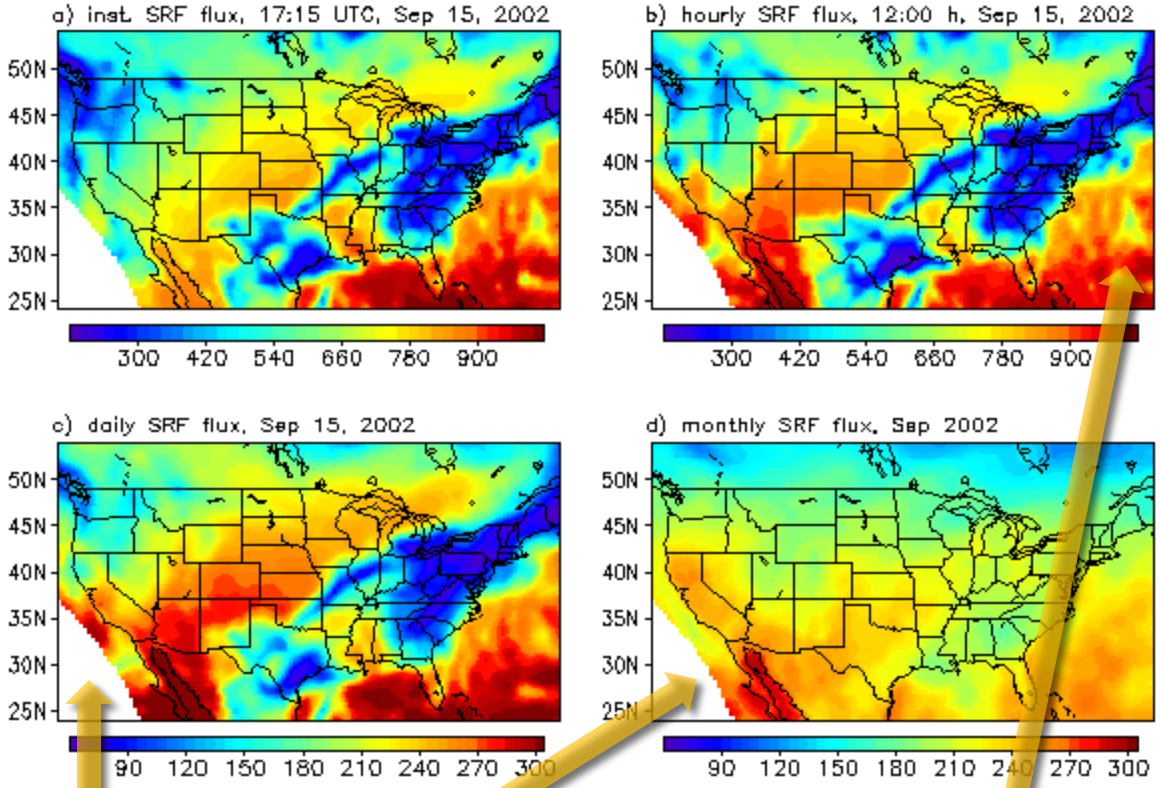


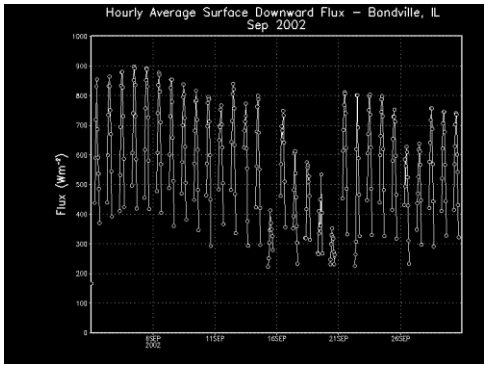
GSIP-fd

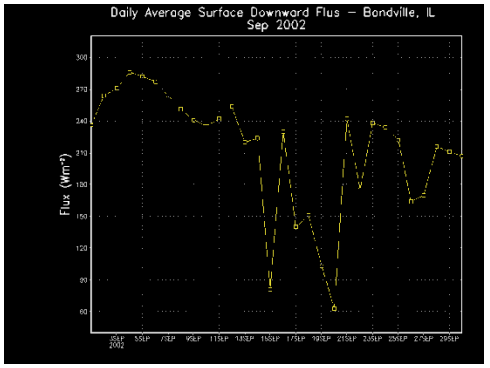


patial resolution will be increased to 4 km from the current value of 14 km in GPSDI project

GSIP-CONUS Product
Hourly/Daily/Monthly Averages





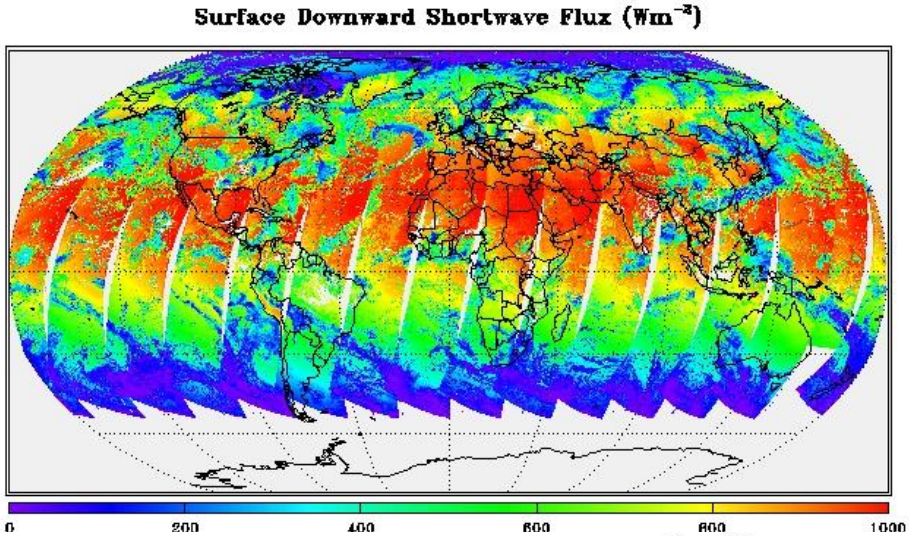


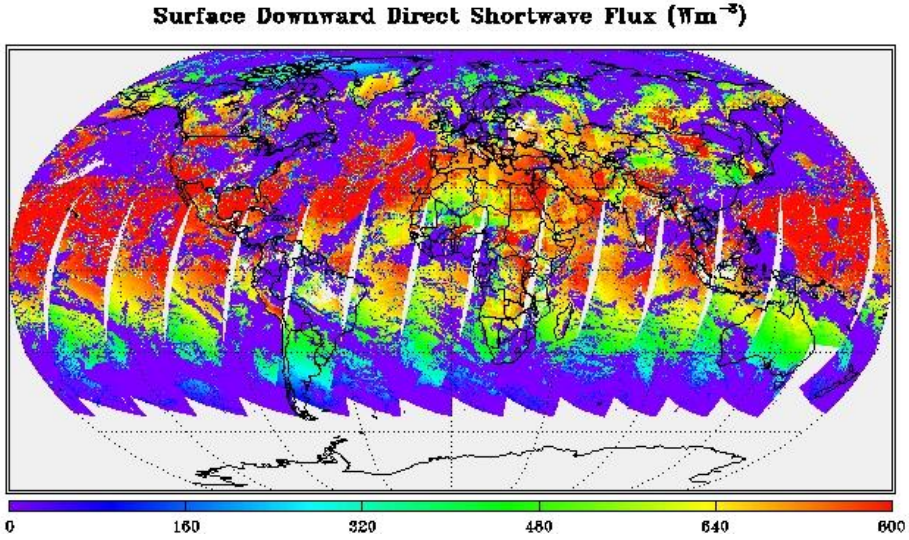
From the instantaneous GSIP-CONUS data hourly, daily and monthly averages are calculated.

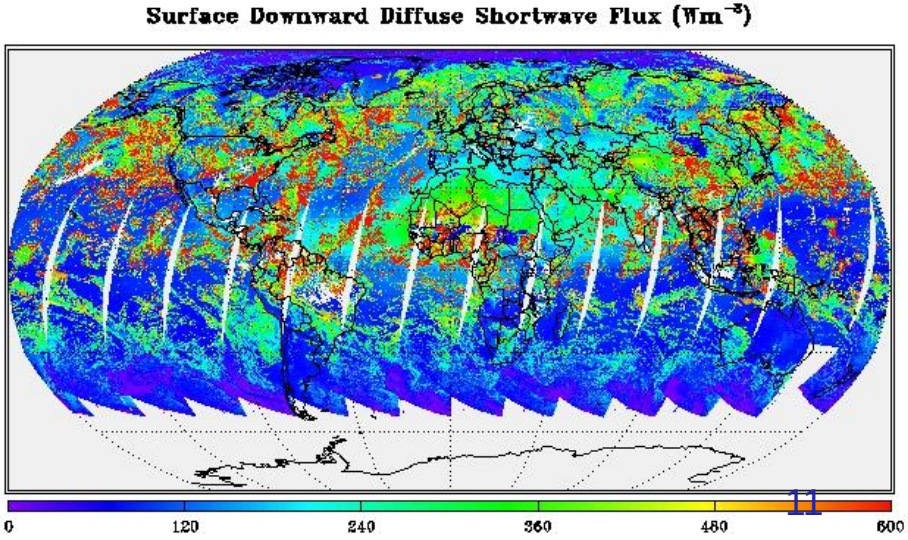
Hourly and daily averages for Bondville, IL for September 2002

ABI SE Example
Total, Direct & Diffuse Radiation

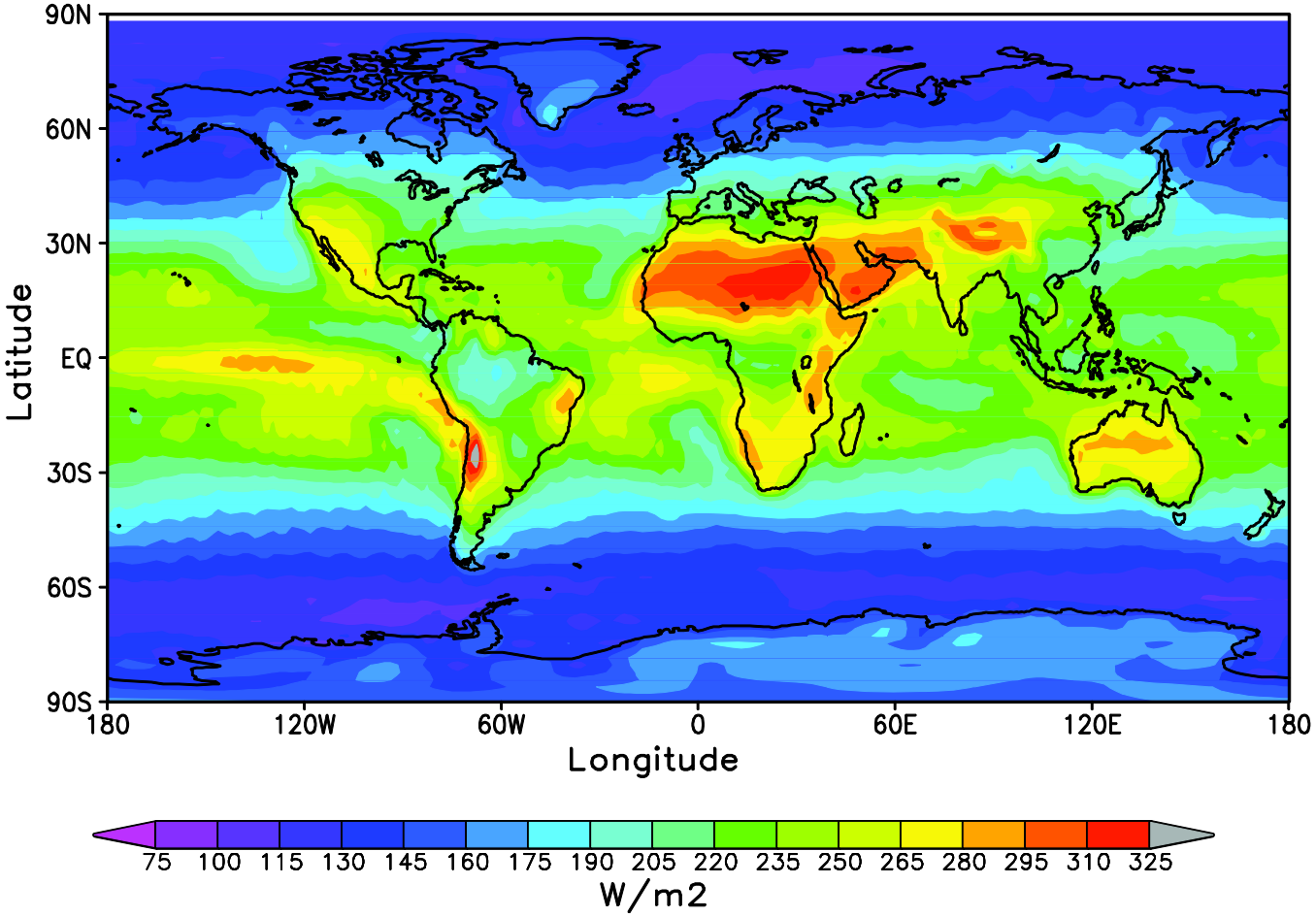
Date: June 11, 2009
Input satellite data: MODIS Terra
Spatial resolution: 5-km



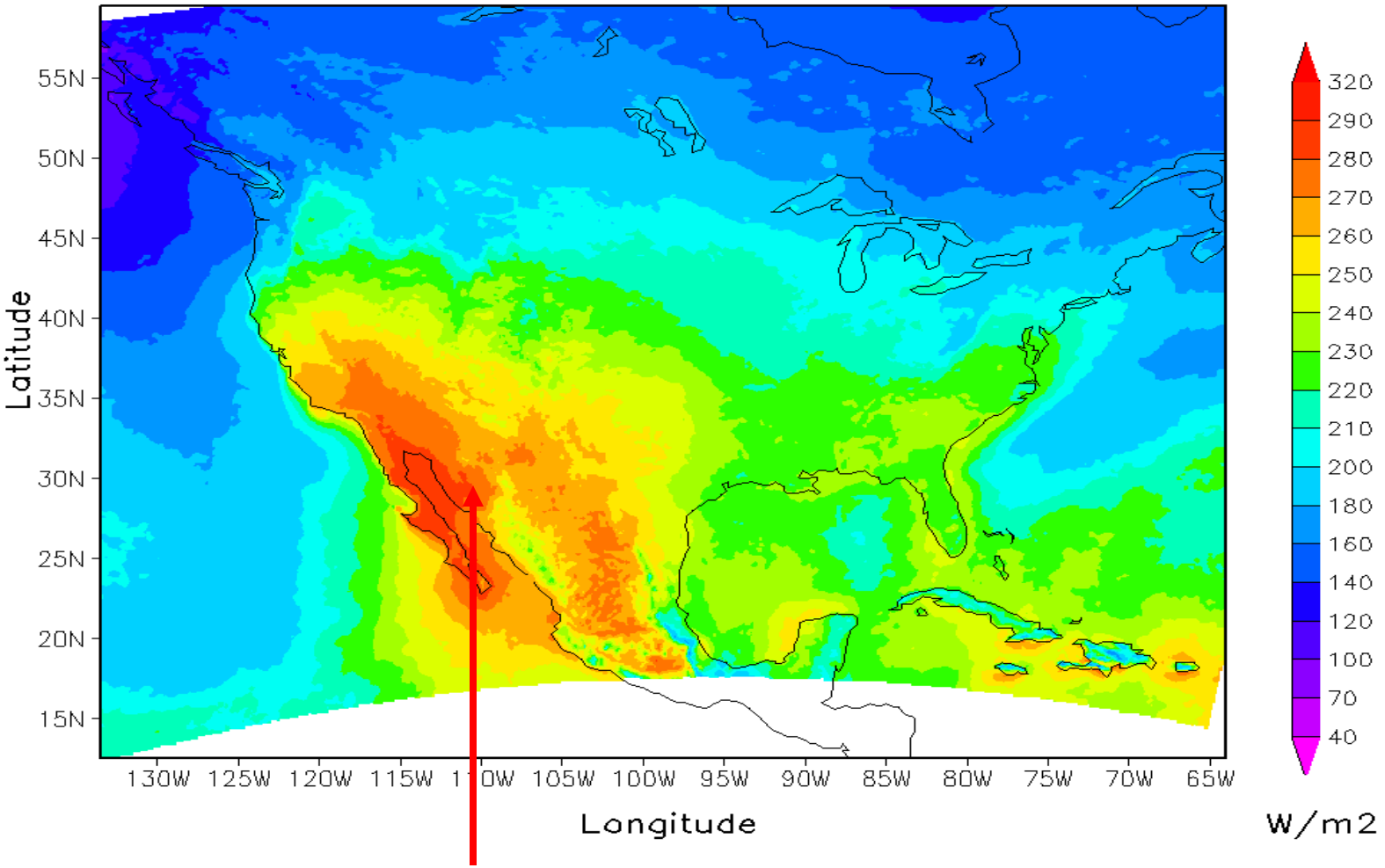




Downward surface solar radiation flux (NCEP,1999-2008)



Solar Energy, North America



South-west of the United States has plenty solar energy.

Wind Energy

Wind Power Calculation

The wind power density (for a unit area and per second) is

$$Power = \frac{1}{2}\rho V^3 \qquad \textbf{(1)}$$

Where V is a wind speed. Using a temperature T and a pressure P,

$$Power = 0.61125 \times \frac{P}{101325}\frac{288.15}{T}V^3 \qquad \textbf{(2)}$$

The wind power density is proportional to a cubic law of the wind speed. **Due to the non-linearity, an energy pattern factor (Epf) is applied when a mean speed (V_a) is used.**

$$Power = Epf \times 0.61125 \times \frac{P}{101325}\frac{288.15}{T}V_a^3 \qquad \textbf{(3)}$$

The energy pattern factor depends strongly on meteorological conditions and topography.

Site	Annual Average Wind Speed at 10 m (m/s)	Epf	Wind power density (W/m2)
Culebra, Puerto Rico	6.3	1.4	220
Tiana Beach, New York	6.3	1.9	285
San Gorgonio, California	6.3	2.4	365

For a same mean wind speed, wind power can differ more than 50% (Gipe, 2004).

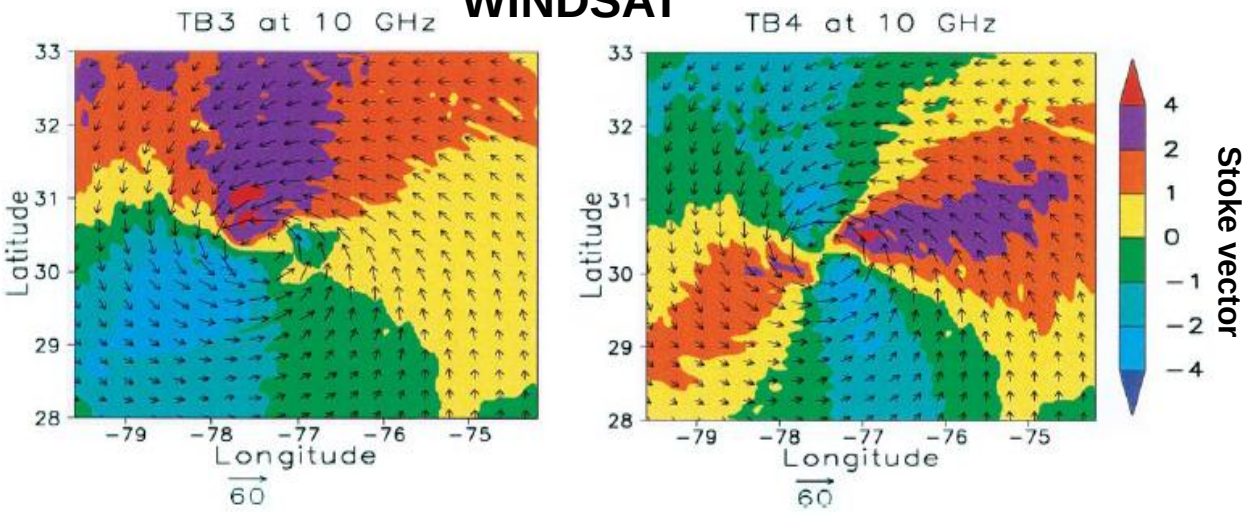
Offshore high-spatial wind field from microwave/radar measurements

1) **An Advanced Synthetic Aperture Radar (ASAR), operating at C-band, has a high-spatial resolution of 30m x 30m. The measurements can be used to derive sea surface roughness which is a function of the sea surface wind vector.**

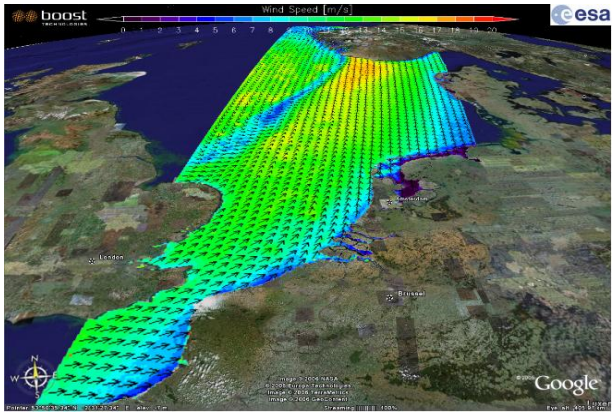
2) **Quick Scatterometer and Advanced Scatterometer (ASCAT) provide global sea surface wind vectors at a resolution of 25 km.**

3) **Passive sensor WINDSAT provides also global wind vectors. The first space-borne polarimetric microwave sensor can obtain a hurricane's wind field.**

WINDSAT

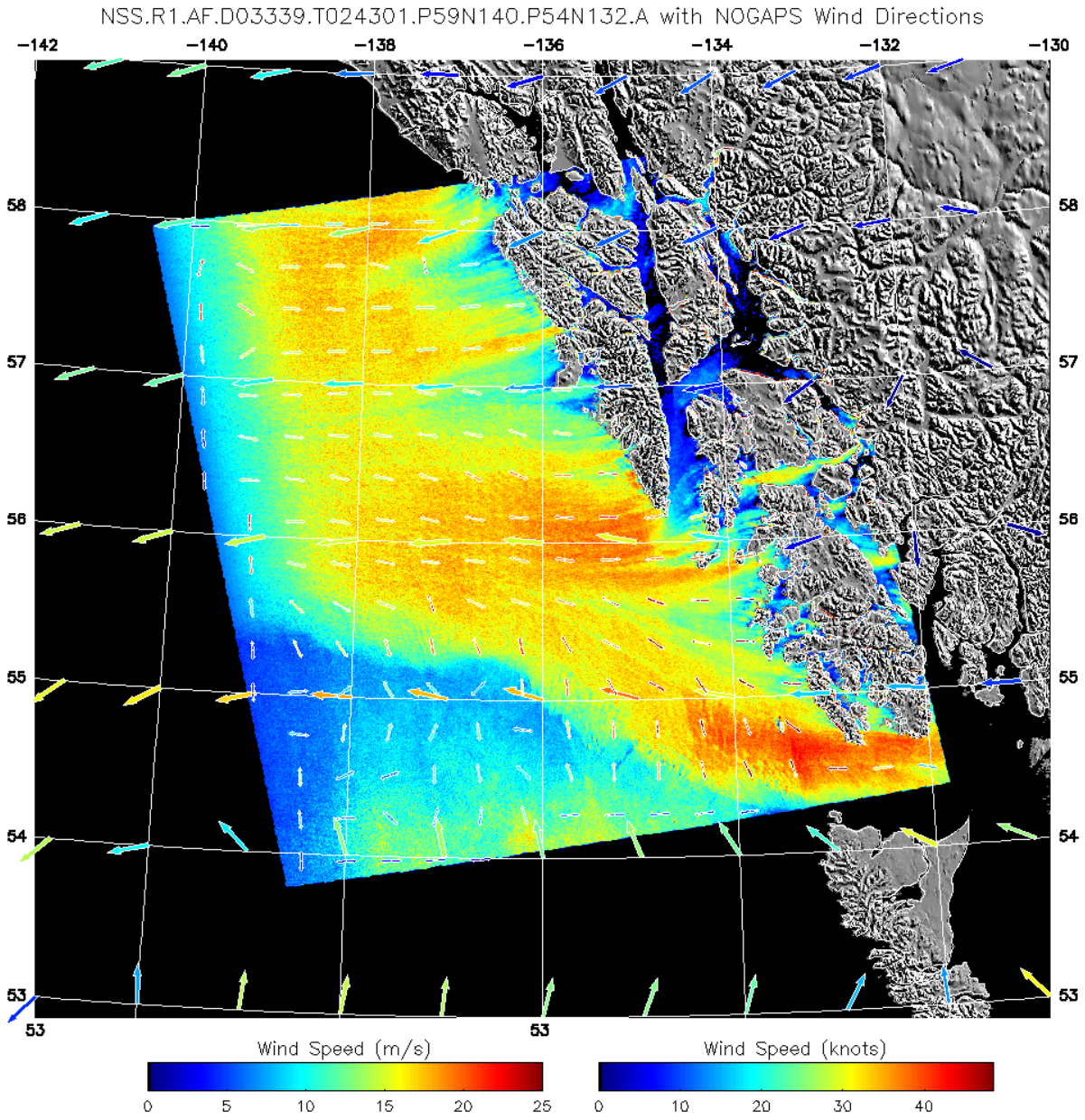


ASAR



ENVISAT ASAR level2 wind field mapped in Google Earth

SAR Coastal Winds for Offshore Wind Farm Applications



SAR Wind Image

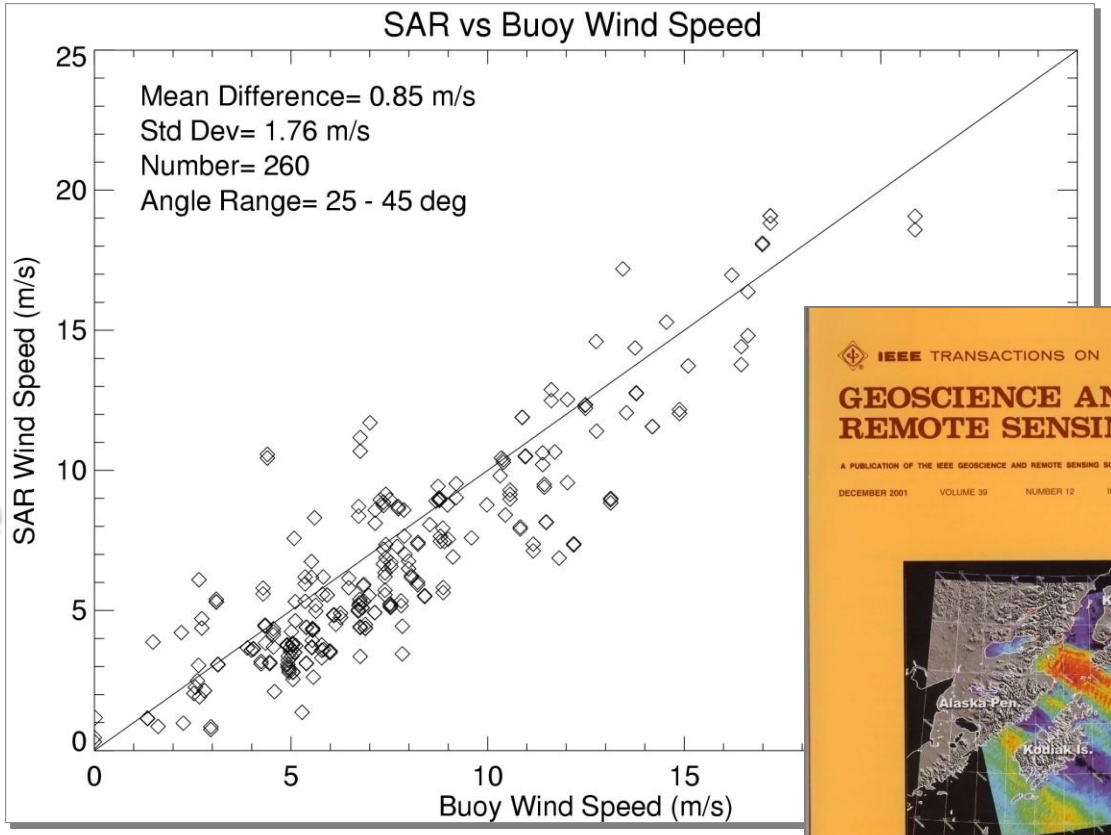
Baranof Island

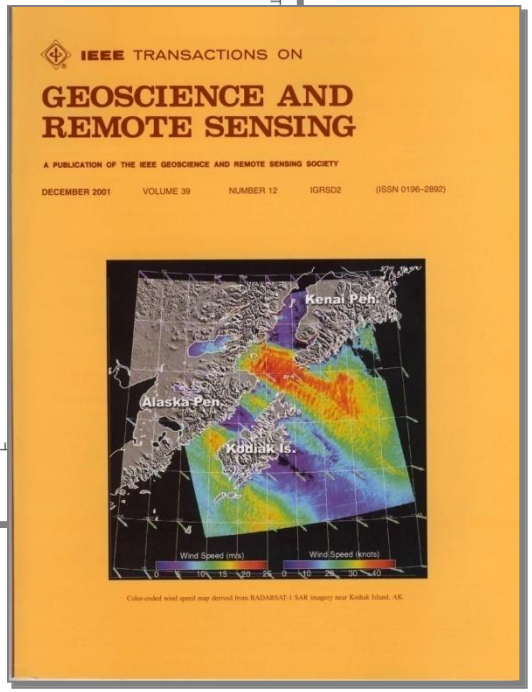
Radarsat-1
05 Dec 2003
04:43 UTC

Winds calculated with APL/NOAA SAR Wind Retrieval System (ANSWRS)

SAR WIND/BUOY WIND COMPARISONS

Include angles > 25° and assume α=0.6. The standard deviation is *1.76* m/s.





Published in *IEEE Transactions Geoscience and Remote Sensing*, December 2001.

Summary - Unique Remote Sensing Capabilities of SAR

- **Measurement of sub-kilometer-resolution winds in coastal areas**
- **Resolve detailed storm and frontal morphology**
- **Reveal many marine atmospheric boundary layer processes**
- **Minimal observing restrictions concerning time of day or weather conditions**

More wind measurements from space

ADM-Aeolus (Atmospheric Dynamics Mission) will carry a Doppler wind lidar at a wavelength of 355 nm to measure global wind-profiles by analyzing the received Doppler shift of the backscattered signal with respect to the frequency of the transmitted laser pulse.

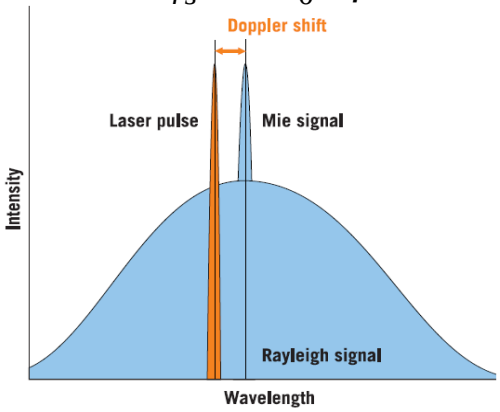
Mission Objectives

- To measure global wind profiles up to an altitude of 30 km
- To measure wind to an accuracy of 1m/s in the planetary boundary layer (up to an altitude of 2 km)
- To measure wind to an accuracy of 2 m/s in the free troposphere (up to an altitude of 16 km)
- To determine the average wind velocity over 50 km tracks.

The data are unique but sparse (2880 profiles per day). Data assimilation is necessary to produce an analysis for a high-resolution forecasting.

Wind speed relative to receiver

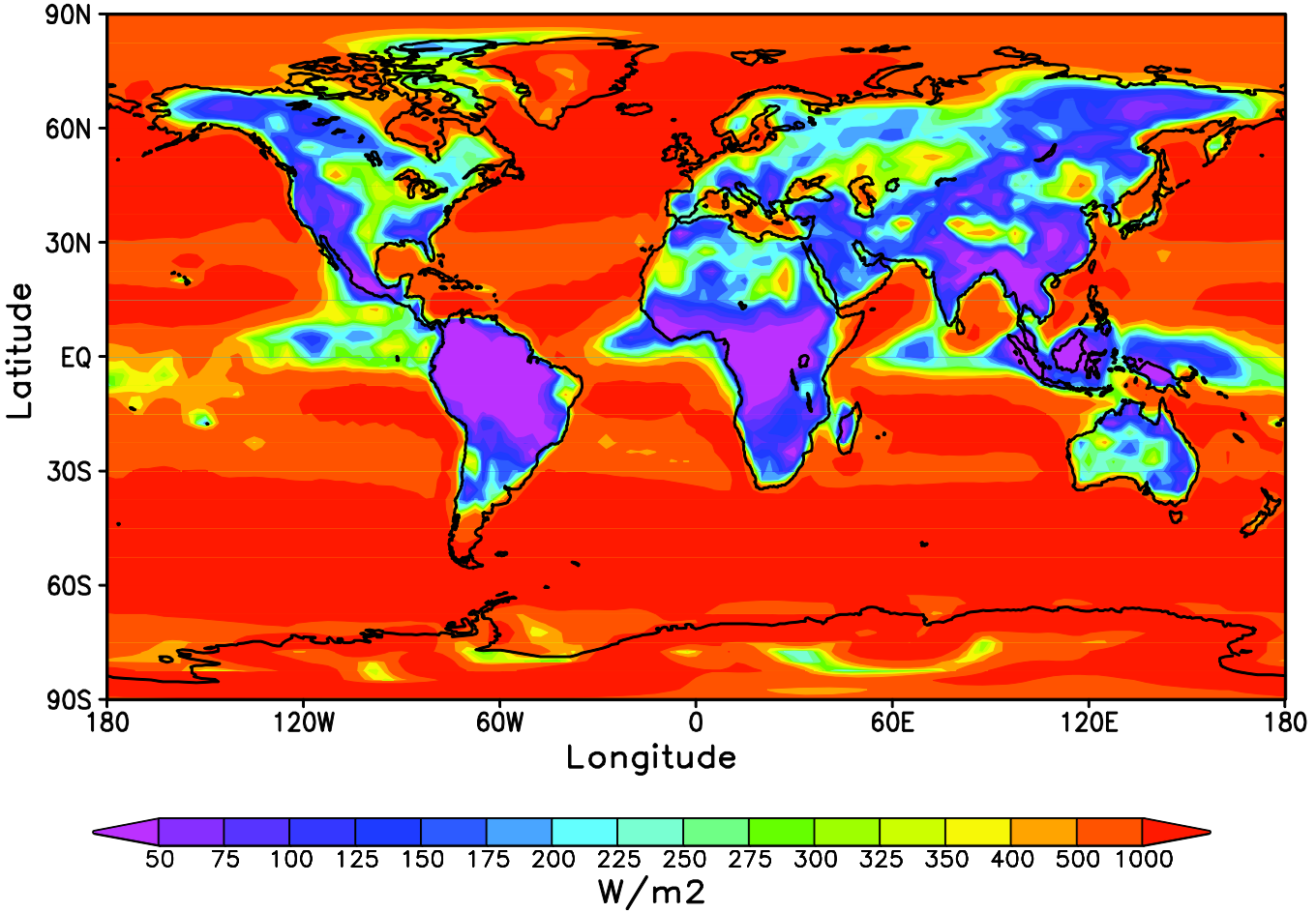
$$V_{rs} = -\lambda_0 \, \Delta f$$



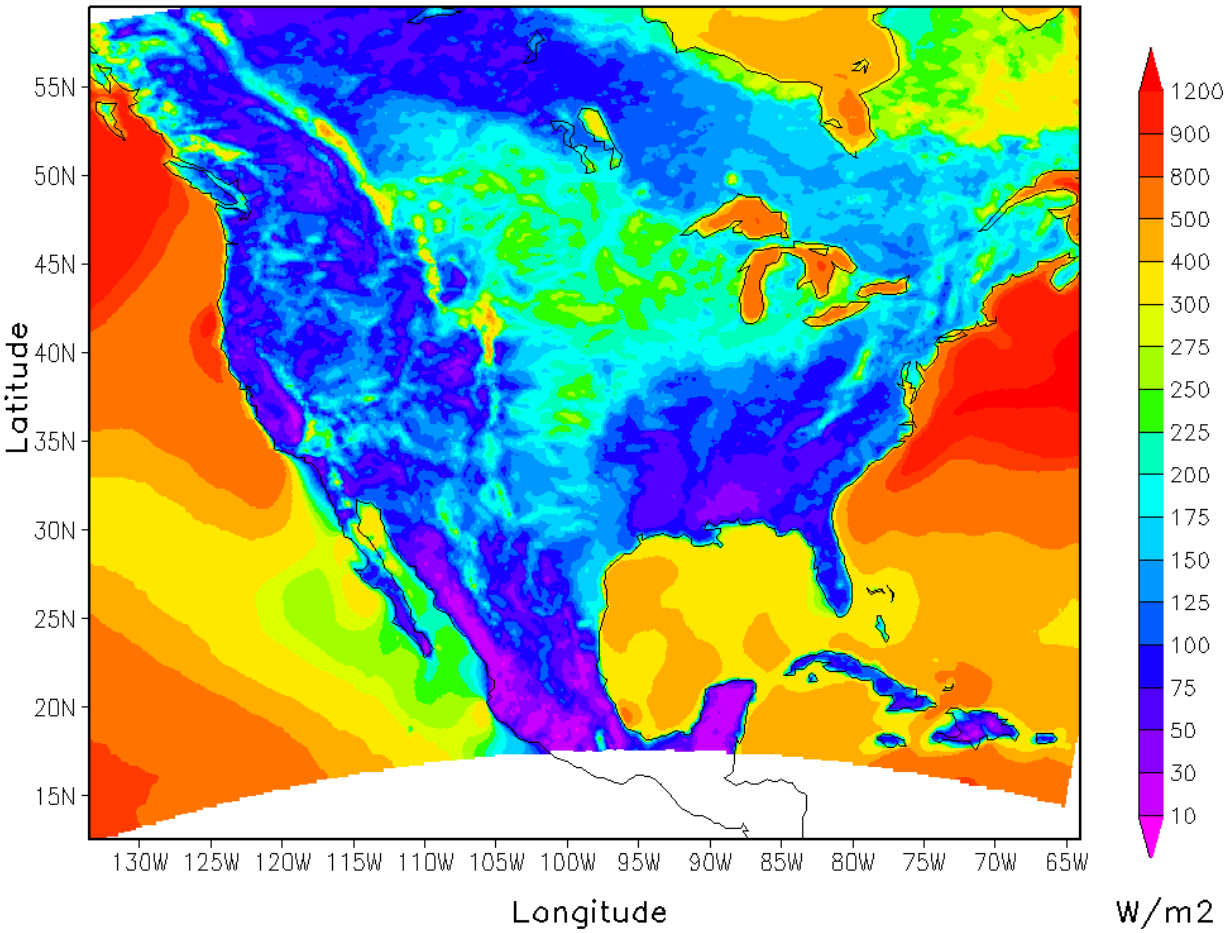
The relative motion of air leads to two effects - the centre frequency of the backscattered light is shifted with the wind velocity in the measurement direction, and the random motion of the air molecules leads to a broadening of the frequency width for the backscattered Rayleigh signal.

ESA document, 2005

Wind energy (1999-2008)



Wind Energy Density at 50 m, North America



The incoming solar energy within this selection-box would supply enough electricity for the American people

http://www.renewableenergyst.org/REST_Home.php

Click and draw a rectangular region

Northern 34.95799531086792

Western -110.720214843 -108.836059570: Eastern

34.33890040040499 Southern

229.7619047619	4.674e+12	1.161e+4	0.2
Energy W/m2	Annual Electricity kWh	Area (km2)	Efficiency Factor

or: Enter an address Go

This example using the web tool shows that one can type in an address, zoom in/out, and draw an area (blue rectangular box).

The tool will show the latitude and longitude, averaged power over the selected area, annual electricity to be produced, area in square kilometers, and the efficiency factor (default or you choose).

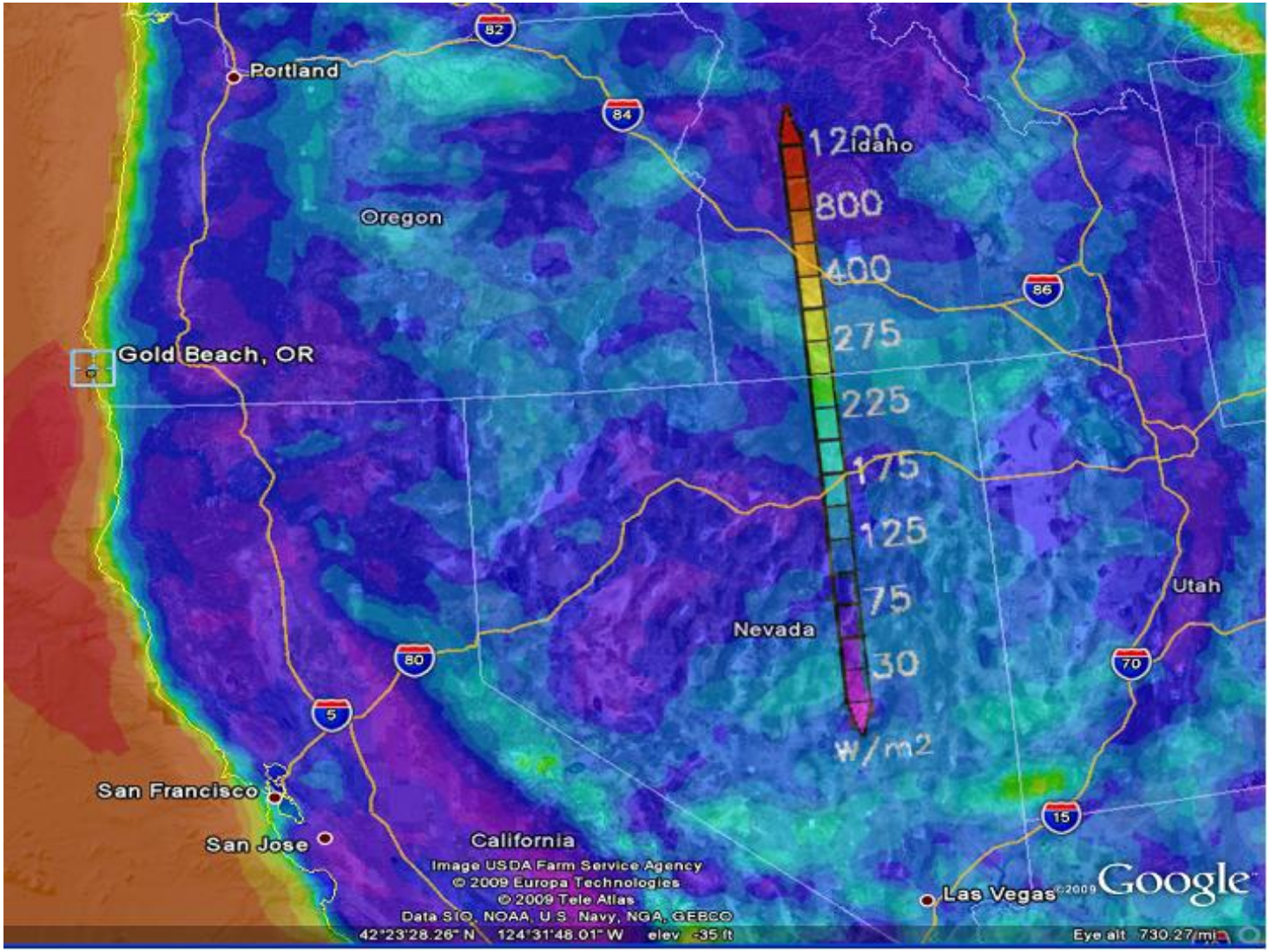
Table 2. Proposed location name, area, and amount of annual solar energy at the surface.

Name	Proposed area (km^2)	Annual Energy (joule)
Sahara	2,000,000	1.71×10^{22}
Arabian Desert	500,000	4.19×10^{21}
Qinghai	1,400,000	1.17×10^{22}
Australia	2,400,000	1.87×10^{22}
Southern South America	1,800,000	1.40×10^{22}
Brazil	600,000	4.77×10^{22}
United States & Mexico	1,600,000	1.25×10^{22}
Southwest Asia	1,200,000	1.00×10^{22}

U.S. Annual electricity consumption: 3.9 TkWh

Liu et al., 2009: Environment & Energy.

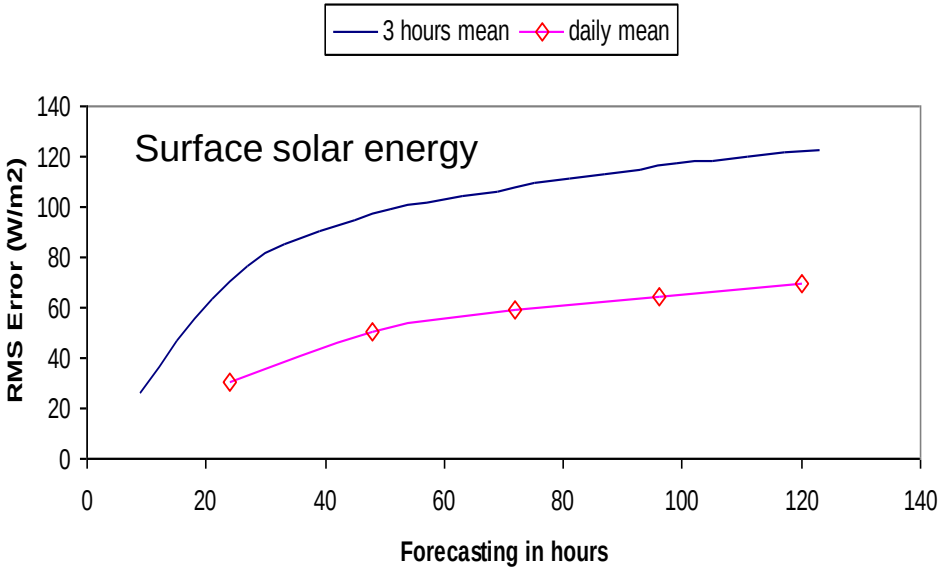
Remote sensing data with GIS for offshore wind farm

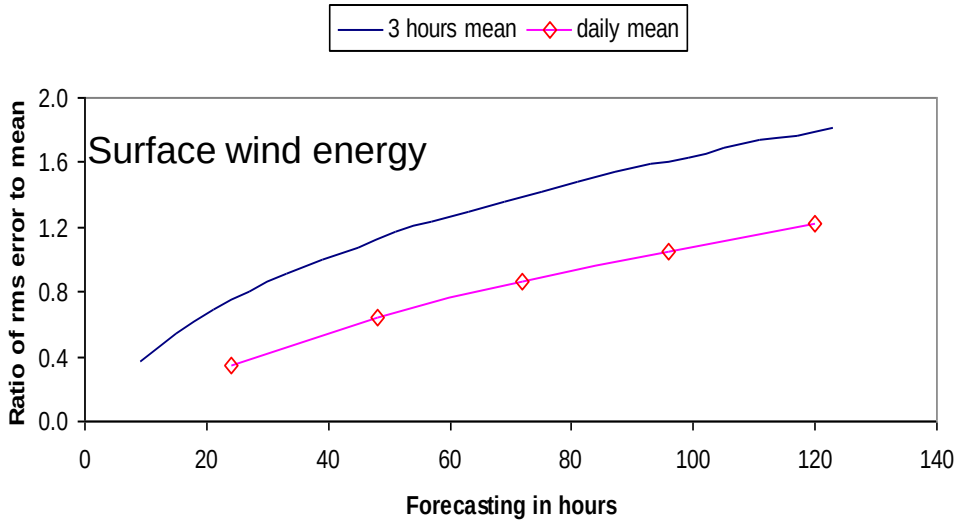


Solar and Wind Energy Forecasting

Daily and 3-hourly forecasts

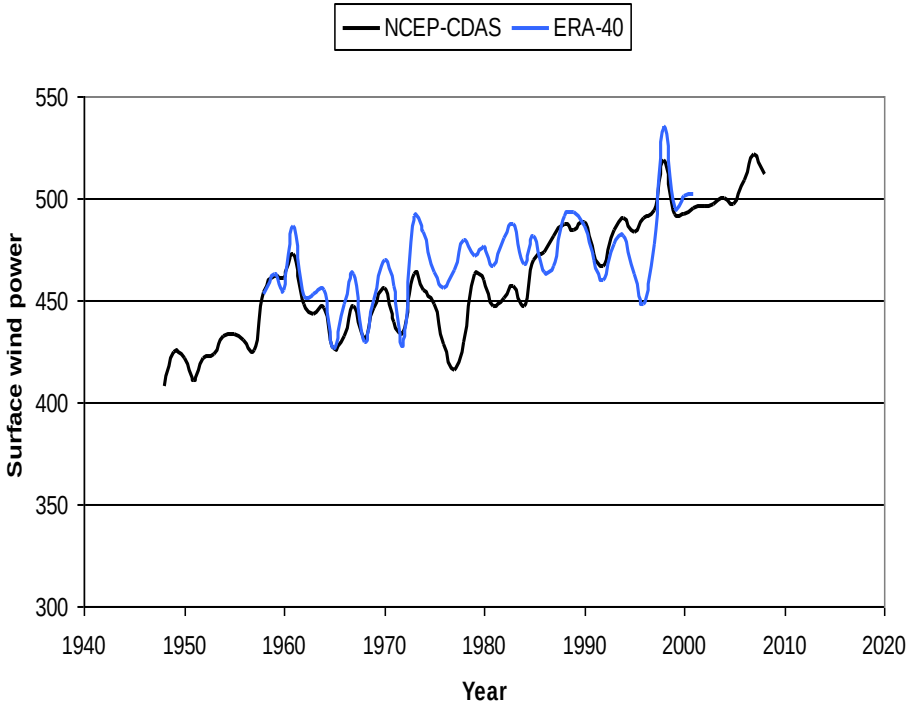
- Using NCEP GFS data, solar energy forecast is promising. Improvements are under consideration.
- Using NCEP GFS data, wind energy forecast is encouraging. Improvements are in high demand.

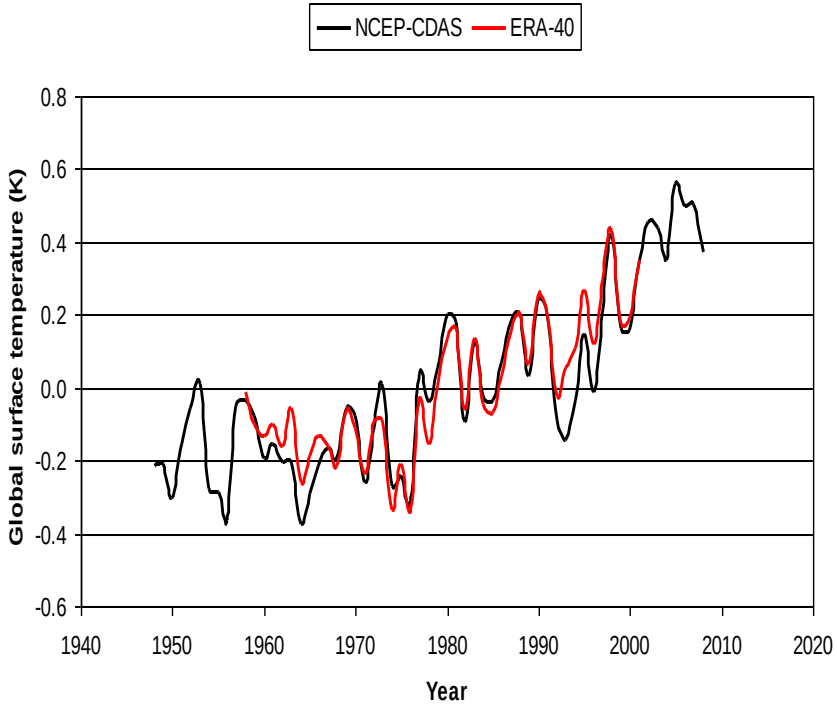




Liu et al., 2009: JRSE

Trend in surface wind power and temperature



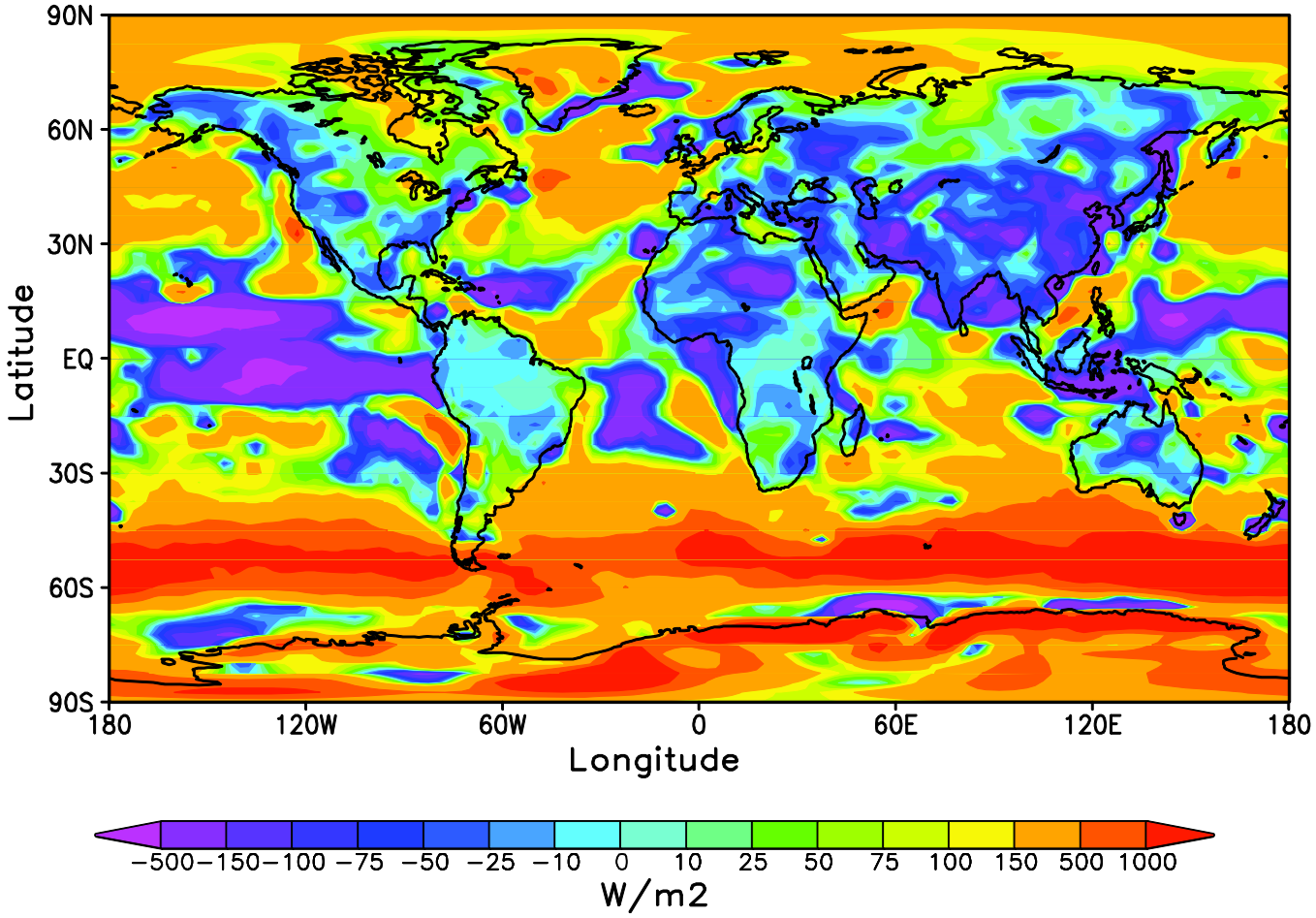


Increasing trends in wind energy and surface temperature are due to climate change.

Knowledge of these climate changes aides in planning renewable energy resources for the future.

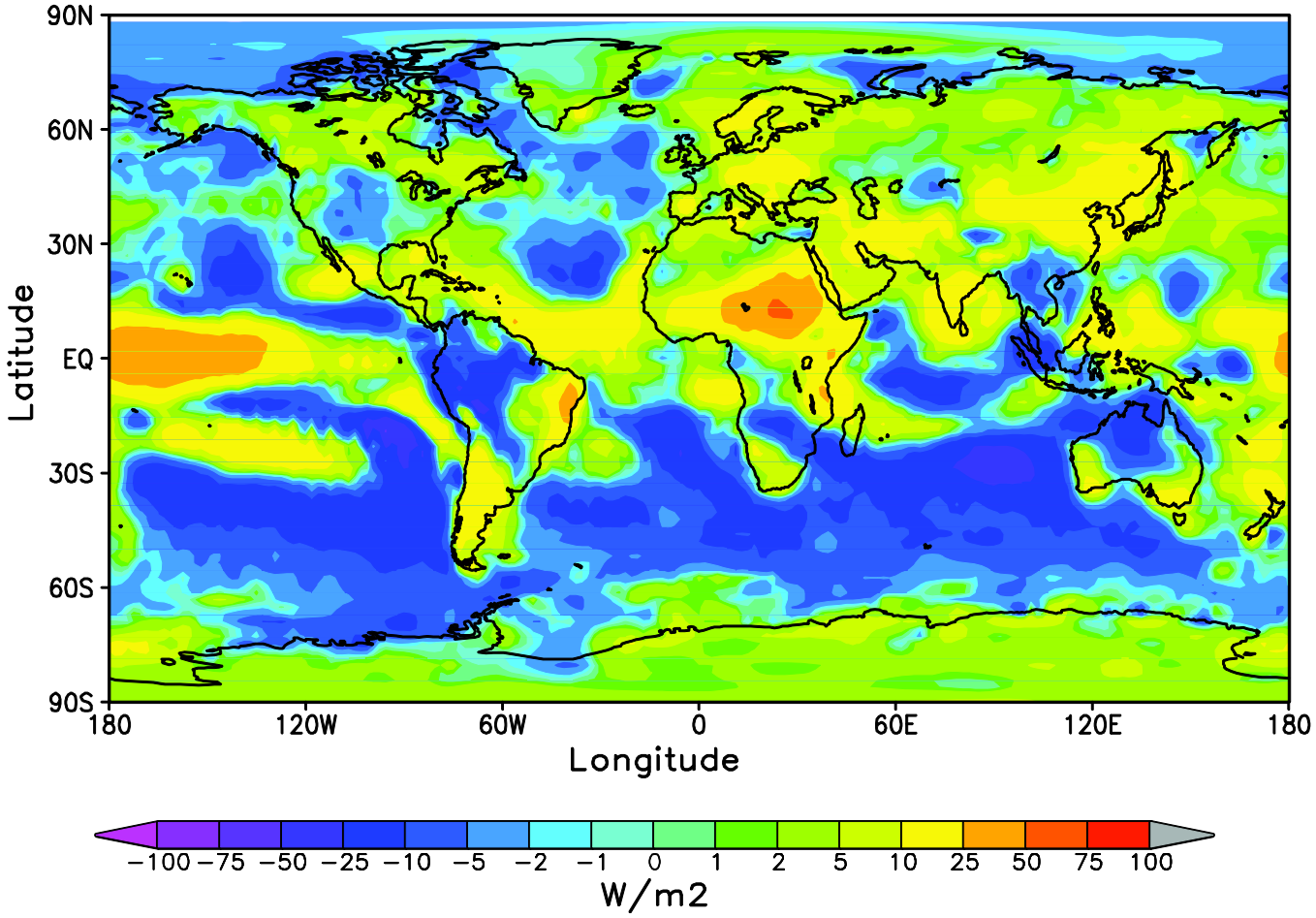
Surface wind energy difference

(1999~2008)- (1949~1958)



Downward surface solar radiation flux change

(1999~2008)-(1949~1958)



Discussion

- Higher spatial resolution of satellite radiation budget measurements is needed.
- Satellite observations of surface winds over land is still challenging.
- Accurate radiative transfer schemes is needed for direct and total, ultraviolet and visible downward flux calculations.
- Advanced data assimilation schemes in global and regional forecast systems will improve energy forecasting.
- Future renewable energy applications will need to respond to changes in climate.